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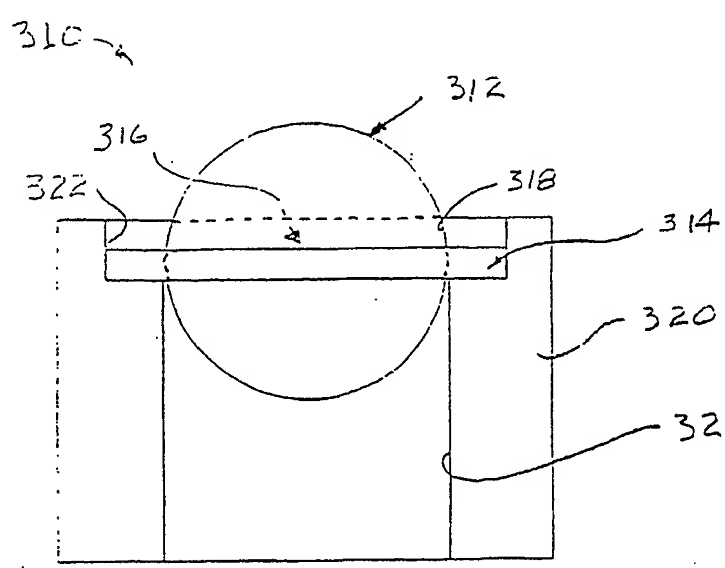

(57) Abstract

A non–corrosive metallic sealing assembly is disclosed having a super–elastic component made of, e.g., nitinol. The super–elastic component (314) can expand or contract to form a seal, preferably upon mechanical stress activation using interference fit with one or more other components of the assembly. The improved seal is useful in fluid connectors such as hoses, electrical connectors, torque transmission devices, in vibration–dampening devices, and hinge or ball and socket joints. The assembly can seal against other components having different coefficients of thermal expansion or contraction, offering reduced temperature sensitivity during seal formation and at high performance operating conditions.

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STRESS-INDUCED SEAL

Technical Field

The present invention relates generally to metallic shape memory seals, particularly those having one or more components made of material that possesses super-elastic properties suitable for high-performance industrial applications that involve differing ranges of operating temperatures and component materials being sealed.

Background

The use of metallic shape memory material, such as Ni-Ti (nitinol) and other bi- or tri-metal alloys, has been documented in a variety of technical applications, including fasteners, connectors, clamps and seals. Many such uses have required temperature in order to activate the shape memory material and change its physical state, while others have used mechanical forces that impart stress to cause a super-elastic physical deformation in the material. Still others have employed a combination of temperature and mechanical stress causing a shape memory effect to function in a desired product. However, not all shape memory materials are super-elastic, because not all exhibit elastic behavior at their operating temperatures. Of particular concern to the instant inventor is the applicability of this technology to the formation of seals. The use of non-corrosive, metallic super-elastic material offers a decided advantage in high performance sealing environments, versus pliable synthetic rubber or silicone materials, in its ability to withstand a more substantial sealing load under extremes of pressure and temperature without drying the way rubbers and silicones can.

U. S. Patent No. 4,896,955 to Zider and Krumme, entitled "Eyeglass Frame Including Shape Memory Elements", characterizes the use of nickel-titanium shape memory alloys that have *super-elastic* or *pseudo-elastic* properties. In criticizing these materials, it is said that the effective useful temperature range for such purely pseudo-elastic components in eyeglass frames is too narrow. This limitation was further said to be remedied by fabrication of such components from materials having "optimized elasticity" properties, that is, work-hardened shape memory alloys. In *U. S. Patent Nos. 5,395,193 and 5,584,631*, also co-invented by *Krumme*, the aforementioned optimized elastic materials are further incorporated in a Belleville fastener said to be useful in eyeglass frames.

U. S. Patent No.5, 683,404 to Johnson, entitled "Clamp and Method for its Use", further discusses shape memory materials that are "pseudo-elastic", defining these materials in terms of their ability to exhibit super-elastic/pseudo-elastic recovery characteristics at room temperature. Such materials are said to deform from an austenitic crystal structure to a stress-induced structure postulated to be martensitic in nature, returning thence to the austenitic state when the stress is removed. The alternate crystal structures described are further said to give the alloy super-elastic or pseudo-elastic properties. Poisson's Ratio for nitinol is about 0.3, but this ratio significantly increases up to approximately 0.5 or more when the shape memory alloy is stretched beyond its initial elastic limit. It is at this point that stress-induced martensite is said to occur, i.e., the point beyond which the material is permanently deformed and thus incapable of returning to its initial austenitic shape. A special tool is employed by *Johnson* to impart an external stretching force that deforms the material which force is then released to cause the material to return to its original condition. While the device is stretched, a member is captured by it and securely clamped when the stretching force is released. This activation of the shape memory component is by application of an external force to that component, rather than activation of one component by another. Another use envisioned by the aforementioned inventor is to connect the modular components of a medical device, as described in *U. S. Patent No. 5,858,020*, by subjecting a component made of shape memory material to an external, i.e., stretching stimulus. A binding or strap device is described in *U. S. Patent No. 5,766,218*

to Arnott, ostensibly to provide compressive force via a tensioning loop member of shape memory material. However, such clamping operations require a special tensioning tool and means on the device to attach the tool and impart a stretching/tensioning force.

In *U. S. Patent No. 5,197,720 to Renz, et al.*, a work piece is held within a clamping tool by an expansion element made of shape memory material that is activated by mechanical force. In this way, torque is transmitted through the shape memory member. *U. S. Patent No. 5,190,546 to Jervis* discloses insertion into a bone cavity of a member made of shape memory material. The walls of the bone cavity are said to impart a compressive force on the member due to interference fit, to cause it to deform and be held in tension within the cavity. The ability of bone matter to withstand such an insertion force without cracking seems highly improbable; indeed, there is no evidence presented that such a result does not occur in the body.

Others have sought to utilize the properties of shape memory materials as locking, connector and bearing elements, e. g., *U. S. Patent Nos. 5,507,826 to Besselink, et al., 5,779,281 to Kapgan, et al.,* and *5,067,827 to Arnold,* respectively; however, such approaches have required temperature to be applied during use. *U. S. Patent Nos. 5,277,435 to Kramer, et al.* and *5,876,434 to Flomenblit, et al.* similarly relied upon temperature to activate the shape memory effect. Such dependence on extrinsic activation by temperature introduces an added process step and may further be disadvantageous in certain other applications, e.g., seals, where temperature extremes are ordinarily encountered during conditions of use.

U. S. Patent No. 5,842,312 to Krumme, et al., entitled, "Hysteretic Damping Apparati and Methods", employs shape memory tension elements to provide energy dissipation. Such elements can be placed between building structures, etc., which are subject to vibration, serving to absorb the energy created by their relative movement. However, this patent does not contemplate the vibration dampening effect of a super-elastic material in the formation of a seal.

None of the above-mentioned prior approaches have contemplated the formation of an effective seal such as envisioned by the present inventor. Moreover, the aforementioned *Renz, et al* patent, although transmitting torque through a work piece, does not contemplate doing so while forming a seal. Further, a key feature of certain seals is their ability to accommodate changes of differing kinds in the members being sealed, such as thermal expansion. Pliable rubbers and silicones, for example, have this characteristic; however, the operating demands are decidedly different in high performance metallic sealing applications.

Prior approaches to the formation of seals from shape memory alloys will now be addressed.

Reference is now made to *U. S. Patent No. 5,862,995 to Wu, entitled, "High Pressure Fluid Passage Sealing for Internal Combustion Engine Fuel Injectors and Method of Making Same"*. In this patent, a shape memory alloy plug is inserted into an open end of a fuel passage, undergoing a metallurgical phase change from martensite to austenite to effect a seal with the passage. This is done by pre-straining the plug when it is cooled within a temperature range of minus 100 to minus 80 degrees Celsius. *U. S. Patent No. 5,226,683 to Julien, et al., entitled, "Reusable Metallic Seal Using Memory Metal"*, employs an annulus of binary metal in the martensite state that is positioned for use, then heated above a transition temperature to an austenite state for removal and reuse. In *U. S. Patent No. 4,281,841 to Kim, et al., entitled, "O-Ring Sealing Arrangements for Ultra-High Vacuum Systems"*, a heat-recoverable tube is chilled to its martensitic state, then deformed, and returned to its austenitic state by means of temperature activation.

However, all of the above attempts involved temperature changes to a shape memory material. The material is initially in an austenitic state, then chilled to a martensitic physical state where it becomes malleable, i. e., not elastic. It is important to note that this process step occurred before a seal was formed. The material was subsequently formed into an intermediate shape and placed into the sealing assembly. The temperature

was raised above the austenite transition temperature where the material recovered towards its original austenitic shape and size, effecting a seal.

Accordingly, there is a need to form a durable, non-corrosive metallic seal or plug, beginning with a shape memory material in its austenitic state and inducing a super-elastic behavior via stress-induction to form an effective high performance seal.

There is a further need to form a seal that decreases the temperature sensitivity of a component made from a shape memory material.

There is still a further need to form a pre-tensioned, stress-induced seal using a super-elastic alloy that adjusts for differences in thermal coefficients of expansion or contraction of dissimilar materials comprising those components being sealed.

There is still a further need to form a pre-tensioned seal that allows for vibration dampening through a sealed member.

There is still a further need to form a pre-tensioned seal that allows for torque to be transmitted through a sealed member.

Summary of Invention

According to the present invention, a seal forming assembly has at least two components. A first component defines a given shape with a cross section having a first dimension. A second component defines a second given shape having a cross section which is continuous with at least a second dimension sized with interference to the first dimension, the second component being made of a super-elastic alloy. One of the first and second components includes an opening that corresponds to its associated cross-section wherein relative motion causes the first dimension to contact the second dimension, imparting a

force to super-elastically expand or contract the second dimension, allowing them to be jointly retained.

In another embodiment of the present invention, a seal forming assembly has a first component defining a given shape with a cross section having a first dimension. A second component defines a second given shape having a cross section which is continuous with at least a second dimension sized with interference to the first dimension, the second component being made of a super-elastic alloy. One of the first and second components includes an opening that corresponds to its associated cross-section wherein relative motion causes the first dimension to contact the second dimension, imparting a force to super-elastically expand or contract the second dimension, allowing a third component to be jointly sealed.

In another embodiment of the invention, a seal forming assembly has a first component defining a given shape with a cross section having a first dimension. A second component defines a second given shape having a cross section which is continuous with at least a second dimension having a size without interference to the first dimension, the second component being made of a super-elastic alloy. One of the first and second components includes an opening that corresponds to its associated cross-section wherein a force causes the second dimension to super-elastically expand or contract, contacting the first dimension effecting a seal.

In a preferred embodiment, the first dimension is greater than the second dimension and the force causes the second dimension to expand.

In another preferred embodiment, a mechanism is provided for forcing the first dimension to contact the second dimension, particularly, a mechanical fastener, or a source of hydraulic or pneumatic pressure, or a collet.

In another preferred embodiment, the opening leads into a cavity and either of the first and second component plugs fluid connection into or out of the cavity.

In another preferred embodiment, the opening leads into a bore and the second component establishes a fluid connection through the bore.

According to the invention, a method of forming a seal assembly is provided. The method has the steps of providing a component made of a super-elastic alloy having a given cross section and applying a force to the cross section, causing it to expand or contract and create a seal.

In a preferred embodiment, the method has the step of providing another component and applying a force to the initial component to create a seal against the other component. It is further preferred that the force is further created by an additional activating component.

An advantage of the present invention is the formation of a high-performance, non-corrosive metallic seal from a shape memory material that can be activated in a variety of uses by mechanical stress in a relatively simple operation while in its austenitic state.

Another advantage is a stress-induced seal using a pre-tensioned shape memory alloy that adjusts for differences in thermal coefficients of expansion or contraction of dissimilar materials comprising those components being sealed.

A still further advantage of the present invention is a high-performance seal that allows for vibration dampening through a sealed member cycling through a super-elastic, stress-strain hysteresis to provide energy dissipation.

Yet a further advantage of the present invention is a high-performance seal that allows for torque transmission through a sealed member.

Other objects and advantages will be appreciated by those skilled in the art, by resort to the appended Drawings having reference numerals that correspond to the ensuing Description wherein the following **Figures** are further elucidated.

Brief Description of the Drawings

Fig. 1 is an exploded external side view of a ball and a super-elastic component (i. e., a washer), shown prior to assembly according to the method of the present invention;

Fig. 2 is a sequential view of Fig. 1, showing the ball fully engaged with the washer to form a seal;

Fig. 3 is a further sequential view of Fig. 2, showing the ball pushed entirely through the washer;

Figs. 4A-4D show various alternative shapes of the super-elastic component;

Fig. 5 is an exploded side view of a ball and super-elastic component (with socket shown in phantom), prior to assembly according to a preferred embodiment of the assembly and method of the present invention;

Fig. 6 is a sequential view of Fig. 5, showing the ball partially engaged with a lip of the socket;

Fig. 7 is a further sequential view of Fig. 6, showing the ball fully engaged with and sealed by the lip of the socket;

Fig. 8 is an exploded perspective view of a hinge component and a super-elastic component in a preferred embodiment of the invention, shown prior to assembly in a preferred method of the present invention;

Fig. 9 is a sequential view of Fig. 8, showing the hinge component fully engaged with the super-elastic component;

Fig. 10 is an exploded sectional view of a preferred sealing assembly of the present invention, showing a ball and a tube having a through-bore with counter-bore in which a super-elastic component is placed, prior to forming a seal between the components;

Fig. 11 is a sequential view of Fig. 8, showing the ball fully engaged with the super-elastic component;

Fig. 12 is a top view of Fig. 11;

Fig. 13 is an exploded side view of a preferred plug assembly of the present invention, showing a component having a cavity with a protrusion over which a super-elastic component and fastening plate mechanism are placed, prior to forming a seal with the super-elastic component;

Fig. 14 is a sequential view of Fig. 13, showing the plate fully engaged with the super-elastic component to form a seal after the plate is fastened down on top of the assembly;

Fig. 15 is a longitudinal cross-section of a preferred hose assembly of the present invention, shown with a super-elastic component placed within one of the hose members prior to engagement of the members;

Fig. 16 is a sequential view of Fig. 15, showing the hose members fully engaged with the super-elastic component to form a seal;

Fig. 17 is an exploded side view, partially in cross section, of a preferred fastener seal of the present invention, showing a super-elastic cover plate prior to engagement over a bolt head in a counter-bore;

Fig. 18 is a sequential view of Fig. 17, showing the plate installed over the fastener head; and

Fig. 19 is an exploded perspective view of an electrical connector assembly of the present invention, showing a super-elastic component prior to engagement of the connector members.

Detailed Description of the Drawings

As shown in Figs. 1-3, 5-7 and 8-9, the inventive sealing assembly and method for its formation is depicted in one or more of its preferred embodiments. The seal forming assembly is generally shown at 10, having at least two components. In Figs. 1-3, a first component of assembly 10 is a ball 12 defining a given spherical shape with a cross sectional diameter having a first dimension D_1. A second component consists of washer 14 defining a second given shape, in this case annular, having a cross section which is continuous with at least a second dimension D_2 sized with interference to the first dimension D_1. One of the first 12 and second 14 components, i. e., washer 14 in Figs. 1-3, includes an opening 16 with an entrance edge or lip 18 that is sized to correspond to its associated continuous cross-section, i.e., the inner diameter D_2. In Fig. 2, relative motion of ball 12 with first dimension D_1 causes it to contact the second dimension D_2 of washer 14, imparting a force to super-elastically expand the second dimension, allowing the ball and washer to be jointly retained in sealing engagement with one another.

Referring still to Figs. 1-3, 5-7 and 8-9, first dimension D_1 is preferably greater than second dimension D_2 and the relative motion of the first 12 and second 14 component causes the second dimension to expand. Although not shown in these Figures, the assembly 10 may be provided with means for creating the relative motion; however, it is possible to impart the necessary force to create the seal using an external source, e. g., a mechanical press.

Washer 14 is preferably an integral member made of a super-elastic alloy, preferably nitinol, more preferably SE508 nitinol. This material is described in *"Nitinol SE508 Data Sheet"*, and is available from *Nitinol Devices & Components, Inc.*, located in Fremont, CA. All of the super-elastic components referred to herein preferably are made of Nitinol SE508.

Experiment 1

Washer 12 of Figs. 1-3 was placed in a mechanical clamping structure (not shown) at room temperature prior to forming the seal assembly 10. Ball 12 was made of polished stainless steel, with a uniform spherical diameter D_1 of .375 inches. The initial resting dimensions of washer 14 were as follows: inner diameter D_2 = .360; outer diameter D_3 = .550; thickness T_1 = .050. Washer 14 was placed under the press with its axial movement constrained by a support plate having an aperture (further not shown) underlying opening 16, the plate limiting the downward motion of the washer. Ball 12 was placed at the entrance to opening 16 and the press engaged to move the ball downward, forcing it into the opening. The super-elastic material of washer 14 was activated by ball 12 in response to the expansion of its inner diameter D_2, by interference with the diameter D_1 of the ball, up to a maximum insertion of the ball as shown in Fig. 2. The outer diameter D_3 of washer 14 was then measured with ball 12 thus inserted and it was observed to increase .014 inches to a new diameter D_2 of .564 inches. That is, the outer diameter D_3 of washer 14 expanded .014 inches, in nearly direct proportion to the difference between the ball diameter D_1 and the inner diameter D_2 of the washer. Neither the diameter D_1 of ball 12 nor thickness T_1 of washer 14 were observed to change. Ball 12 was then pushed completely through the inner diameter D_2 of washer 12, whereupon the dimensions of the washer were measured as follows: outer diameter D_3 = .556; and inner diameter = .367. Therefore, some of the deformation was of a "plastic" nature, that is, the dimensions of washer 14 were permanently altered. Because the super-elastic material was already in the austenitic state, there was no return to the extent of such plastic deformation. A 1-2% dimensional elastic capacity was observed. In order to verify the results above, I

repeated this experiment with a different washer having substantially the same dimensions and observed similar results.

Experiment 2

The same ball 12 and washer 14 from the initial run of Experiment 1 was used to form the assembly 10. I postulated that the maximum plastic deformation had already occurred and, thus, would not further change. It was expected that the washer 14 would preserve its super-elastic properties and continue to admit ball 12 into opening 16, therefore expanding the resting dimensions of the washer in the manner observed for the initial run of Experiment 1. I observed that the inner D_2 and outer D_3 diameters of washer 14 measurably expanded to practically the same dimensions as was observed before, not greater or less. When ball 12 was pushed through opening 16, the same dimensions were observed as at the conclusion of the initial run of Experiment 1. A uniform band or swath 17 (Fig. 3) was observed upon passage of ball 12 through washer 14 (Fig. 3), in the circumferential area of diameter D_1 corresponding to its contact with the super-elastic material of the inner diameter D_2. This indicates that an even seal was effectively formed in a substantial area surrounding the circumference of ball 12, rather than a narrow line of contact. Thus it is concluded that the super-elastic material deformed in response to the stress-activated seal formation by the relative motion, conforming to the contour of ball 12.

With further reference to Figs. 1-3, 5-7 and 8-9, either of the first 12 and second 14 components the assembly 10 may have a tapered lead to facilitate activation of the seal. Lip 18 of opening 16 may have a chamfered entrance edge (not shown), functioning as a lead-in that makes easier the insertion of the first dimension D_1 into the second dimension D_2.

Referring to Figs. 4A-D, either or both of the opening 16 and outer profile of washer 14 may be fabricated in a variety of geometric shapes. Fig. 4A shows the annular shape used

in Figs. 1-18. Fig. 4B shows a washer 14 with an octagonal opening 16 to receive e. g., a torque transmission member (not shown) while its outer profile is circular, e. g., for location of the washer in a counter-bore. Fig. 4E shows a washer 14 having an octagonal cross section. Washer 14 of Fig. 4C has a splined opening 16 for similarly receiving a torque transmission member, while in Fig. 4D both the opening and outer profile have a splined cross section, e. g., to also circumferentially mesh with a torque transmission shaft or other gear arrangement.

In Figs. 5-7, a seal forming ball and socket joint assembly is generally shown at 110. The seal assembly 112 is formed according to the process described above in conjunction with Figs. 1-3 and Experiments 1-2. Referring specifically to Fig. 5, a rod and ball member 112 is positioned with the ball adjacent an opening leading into the socket cavity 119 of member 114 made of super-elastic material. The opening is sized having a diameter interfering with the ball diameter, such that ball 112 activates the super-elastic material of socket 114 (Fig. 6) to expand it and admit the ball until the ball is securely seated within the socket (Fig. 7). The entrance lip 118 of opening 116 may have the same or a different internal radius of curvature as the remainder of the socket, may have a chamfered lead-in, depending upon the particular sealing assembly properties needed.

Figs. 8-9 show a seal forming hinge assembly 210, with a movable cylindrical member 112 and fin 213 sized with a diameter interfering with the diameter of a cylindrical receptacle member 214 having opening 216 with lip 218. Activation of the seal is similar to the process described for Figs. 1-3 and 5-7, as is the sealing function of lip 218 which may have the same or a different internal radius of curvature of the receptacle 214.

Other alternative embodiments of the stress-induced seal will now be described, i. e., those requiring an additional or third component.

In Figs. 10-12, a seal forming assembly is generally shown at 310. Ball 312 and washer 314 are similar to those shown by Figs. 1-3, except they are activated within a third

component represented by body 320 having through-bore 321 and counter-bore 322 within which the washer is placed. Ball 312 passing into opening 316 of washer 314 (Figs. 11-12) induces stress causing the opening to expand radially in the direction of arrows 324. The outer diameter of washer 314 thus expands to engage and form a seal against counter-bore 322, as well as the seal formed between ball 212 and opening 316. The material of the opening 316 deforms to the spherical contour of ball 312, as seen in Fig. 11, forming an effective circumferential area of metallic sealing contact around the ball.

Referring to Figs. 13-14, a seal-forming plug assembly is generally shown at 410. A body 420 has an opening 416 with a protuberance 432 having a wall 422 with an outer diameter D_1, defining an entrance into a cavity 434 to be sealed against fluid escape. The second component is a super-elastic washer 414 having an outer diameter D_3 and an inner diameter D_2. A cover 438 has a circular indentation 436 formed in the undersurface of the cover, the indentation having a diameter D_4.

There are a variety of ways wherein the relative sizing of D_1-D_4, respectively, can be chosen to effect a seal in the embodiment shown by Figs. 13-14 and variations thereof, which shall now be explained. Where D_4 is less than D_3 and D_1 is less than or equal to D_2, the washer 414 is activated to contract and form a seal. Where D_1 is greater than D_2 and D_4 is greater than or equal to D_3, the washer 414 is activated to expand and form a seal. Where D_1 is greater than D_2 and D_4 is less than D_3, the washer is activated in a dual manner to both expand and contract to form a seal. The various sealing arrangements described relative to Figs. 13-14 could further be adapted for use with other embodiments shown elsewhere herein, depending upon the design requirements for a particular seal.

Further referring to Figs. 13-14, there is further provided means for creating the relative motion of the dimensions D_1-D_4, in the form of mechanical fasteners 428 received through holes 431 of cover 438 and threaded into tapped apertures 429 formed in body 420. Such means are not shown in Fig. 19; however, in the case of computer cable

connectors, the conventionally used draw-screw arrangement can be employed. Alternatively, a source of hydraulic or pneumatic pressure (not shown) can be used to effect or assist in effecting the seal formation.

In Figs. 15-16, a hose connector assembly is generally shown at 510, having a mating pair of male 550 and female 552 connector members. A fluid passage 554 is provided through the members 550, 552 and a super-elastic washer 514 is located within a detent 558 in a counter-bore 560 of the female member 552. Mating threads 556 on each member 550, 552 couple the members together similar to the fasteners 428 of Figs. 13-14. A nozzle 562 with tapered lead-in head 564 is positioned adjacent opening 516 of the female member 552 and moved into the opening to engage the inner diameter of washer 514, as shown in Fig. 16. The relative movement induces a stress seal of the outer diameter of washer 514 against counter-bore 560, as well as the inner diameter of washer 514 against nozzle 562, i. e., a dual-activated seal.

Although not shown, the hose members of Figs. 15-15 could be replaced by torque transmitting members, wherein the super-elastic component forms a seal of the members against one another and will transmit torque between them.

Similarly, an assembly could be provided, although not shown, wherein the second component dampens vibration between the first and third components.

Further, the seal forming assembly could be employed where, as in Figs. 13-16, the first and third components may have differing coefficients of thermal expansion or contraction.

The fastening seal assembly is shown in Figs. 17-18. A washer 614 made of super-elastic material is used to seal a fastener 628 received within a threaded aperture 664 formed in a body 650. The body 620 has an opening 616 leading into a counter-bore 622 within which both the head 632 of tightened fastener 628 and the washer 614 are received, as in

Fig. 18. Activation of the super-elastic material of the washer 614 by tightening of bolt 658 into threaded aperture 664 causes outward radial stress that locks its outer diameter against counter-bore 622. The stress activation also causes the inner diameter of washer 514 to contract. In an alternative embodiment (not shown) the opening 616 of washer 614 may be activated to grip the threaded shaft 634, where the washer is located beneath head 632 and pre-assembled with fastener 628 prior to insertion into the opening 616. That is, for use as a locking seal washer.

Referring to Fig. 19, a seal forming electrical connector assembly is generally shown at 710. A mating pair of generally rectangular male 750 and female 752 cable pin connectors, such as for computer peripherals, are brought together with a correspondingiy shaped ring 714 made of super-elastic material between them. Either of the connectors 750, 752 could be sized to accept the opening 716 of ring 714 around its periphery, while the other connector may be provided with an internal groove (not shown) wherein the ring is seated. Dual activation of the inner and outer diameter of ring 714 is similar in manner to the hose connector assembly 510 of Figs. 15-16.

It is further possible, according to the invention, to provide an alternative seal forming assembly having at least two components. A first component defines a given shape with a cross section having a first dimension. A second component defines a second given shape having a cross section which is continuous with at least a second dimension to be sized closely but without interference to the first dimension. Force causes the second dimension to super-elastically expand or contract, effecting a seal with the first dimension. Preferably, the first dimension could be sized greater than the second dimension wherein the force causes the second dimension to expand. The means of providing such force could be a fastener, a source of pneumatic or hydraulic pressure, or a collet. The force could further be transmitted through a third component, or through a composite structure formed on either of the first and second component. For example, the third component could be an intermediate member such as a sleeve, situated in the opening between the first and the second dimension. Alternatively, either the first or

second component, or both first and second components, could be a layered or coated structure of different materials. Although not shown, those skilled in the art will appreciate the modifications mentioned immediately above, in conjunction with the various embodiments described herein. For example, a plugged cavity, a fluid connector, torque transmission, etc., could all be adapted for use with a non-interfering fit between the first, second and third components of the seal forming assembly taught herein.

Therefore, the present invention generally teaches a method of forming a seal assembly employing the steps of providing a component made of a super-elastic alloy with a given cross section, and, applying a force to the cross section, causing it to expand or contract and create a seal. Further, the method may use a step of providing another component and applying a force to the initial component of to create a seal against the other component. The method may also employ the step of providing an additional activating component to cause the force to be applied.

While one or more preferred embodiments of the present invention have been described, it should be understood that various changes, adaptations and modifications may be made without departing from the spirit of the invention and the scope of the appended Claims.

Claims:

1. A seal forming assembly comprising:

a first component defining a given shape with a cross section having a first dimension;

a second component defining a second given shape having a cross section which is continuous with at least a second dimension sized with interference to the first dimension, the second component being made of a super-elastic alloy; and

one of the first and second components includes an opening that corresponds to its associated cross-section wherein relative motion causes the first dimension to contact the second dimension, imparting a force to super-elastically expand or contract the second dimension, allowing a third component to be jointly sealed.

2. The assembly of Claim 1 wherein the first dimension is greater than the second dimension and the relative motion causes the second dimension to expand.

3. The assembly of Claim 1 wherein the first dimension is smaller than the second dimension and the relative motion causes the second dimension to contract.

4. The assembly of Claim 1 wherein the third component is initially sized and shaped to be in an interfering fit with either of the first and second components.

5. The assembly of Claim 1 further comprising means for creating the relative motion to cause the first dimension to contact the second dimension.

6. The assembly of Claim 5 wherein the relative motion means comprises a mechanical fastener.

7. The assembly of Claim 5 wherein the relative motion means comprises a source of hydraulic or pneumatic pressure.

8. The assembly of Claim 1 wherein the opening leads into a cavity and the first or third component plugs fluid connection into or out of the cavity.

9. The assembly of Claim 8 further comprising an electrical connector mechanism.

10. The assembly of Claim 1 wherein the opening leads into a bore and the second component establishes a fluid connection between the first and third components.

11. The assembly of Claim 10 further comprising a hose connector mechanism.

12. The assembly of Claim 1 wherein the second component transmits torque between the first and third components.

13. The assembly of Claim 1 wherein the second component dampens vibration between the first and third components.

14. The assembly of Claim 1 wherein the first and third components have differing coefficients of thermal expansion or contraction.

15. The assembly of Claim 1 wherein either of the first, second and third components has a tapered lead to facilitate activation of the seal.

16. The assembly of Claim 1 wherein the super-elastic material is nitinol.

17. The assembly of Claim 1 further comprising a bolt with a head, wherein the second component is a locking washer that seals as the bolt is fastened.

18. The assembly of Claim 1 wherein the second component comprises a cover for a fastener.

19. A seal forming assembly having at least two components and comprising:

a first component defining a given shape with a cross section having a first dimension;

a second component defining a second given shape having a cross section which is continuous with at least a second dimension sized with interference to the first dimension, the second component being made of a super-elastic alloy; and

one of the first and second components includes an opening that corresponds to its associated cross-section wherein relative motion causes the first dimension to contact the second dimension, imparting a force to super-elastically expand or contract the second dimension, allowing them to be jointly retained.

20. The assembly of Claim 19 wherein the first dimension is greater than the second dimension and the relative motion causes the second dimension to expand.

21. The assembly of Claim 19 wherein the first dimension is smaller than the second dimension and the relative motion causes the second dimension to contract.

22. The assembly of Claim 19 further comprising means for creating the relative motion to cause the first dimension to contact the second dimension.

23. The assembly of Claim 22 wherein the relative motion means comprises a mechanical fastener.

24. The assembly of Claim 19 wherein the relative motion means comprises a source of hydraulic or pneumatic pressure.

25. The assembly of Claim 19 wherein the opening leads into a cavity and the first or second component plugs fluid connection to the cavity.

26. The assembly of Claim 19 wherein the opening leads into a bore and the second component establishes a fluid connection with the first component.

27. The assembly of Claim 19 wherein the second component transmits torque from the first component.

28. The assembly of Claim 19 wherein either of the first and second components has a tapered lead to facilitate activation of the seal.

29. The assembly of Claim 19 wherein the super-elastic material is nitinol.

30. The assembly of Claim 29 wherein the super-elastic material is SE508 nitinol.

31. The assembly of Claim 19 further comprising a hinge joint.

32. The assembly of Claim 19 further comprising a ball and socket joint.

33. A seal forming assembly having at least two components and comprising:

a first component defining a given shape with a cross section having a first dimension;

a second component defining a second given shape having a cross section which is continuous with at least a second dimension sized closely to but without

interference to the first dimension, the second component being made of a super-elastic alloy; and

one of the first and second components includes an opening that corresponds to its associated cross-section wherein a force causes the second dimension to super-elastically expand or contract, effecting a seal with the first dimension.

34. The assembly of Claim 33 wherein the first dimension is greater than the second dimension and the force causes the second dimension to expand.

35. The assembly of Claim 33 wherein the first dimension is smaller than the second dimension and the force causes the second dimension to contract.

36. The assembly of Claim 33 further comprising means forcing the first dimension to contact the second dimension.

37. The assembly of Claim 36 wherein the force means further comprises a fastener.

38. The assembly of Claim 36 wherein the force means further comprises a source of hydraulic or pneumatic pressure.

39. The assembly of Claim 36 wherein the force means further comprises a collet.

40. The assembly of Claim 33 wherein the opening leads into a cavity and either of the first and second components plugs fluid connection into or out of the cavity.

41. The assembly of Claim 33 wherein the opening leads into a bore and the second component establishes a fluid connection through the bore.

42. The assembly of Claim 40 further comprising a hose connector mechanism.

43. The assembly of Claim 33 wherein the second component transmits torque from the first component.

44. The assembly of Claim 33 wherein the second component has a polygonal or splined cross-section.

45. The assembly of Claim 33 wherein the super-elastic material is nitinol.

46. The assembly of Claim 45 wherein the force is transmitted through a third component or through a composite structure formed on either of the first and second component.

47. The assembly of Claim 33 further comprising a hinge joint.

48. The assembly of Claim 33 further comprising a ball and socket joint.

49. A method of forming a seal assembly comprising the steps of:

(a) providing a component made of a super-elastic alloy having a given cross section; and

(b) applying a force to the cross section, causing it to expand or contract and create a seal.

50. The method of Claim 49 further comprising the step of providing another component and applying a force to the component of step (a) to create a seal against the other component.

51. The method of Claim 49 wherein the force of step (b) is further created by an additional activating component.

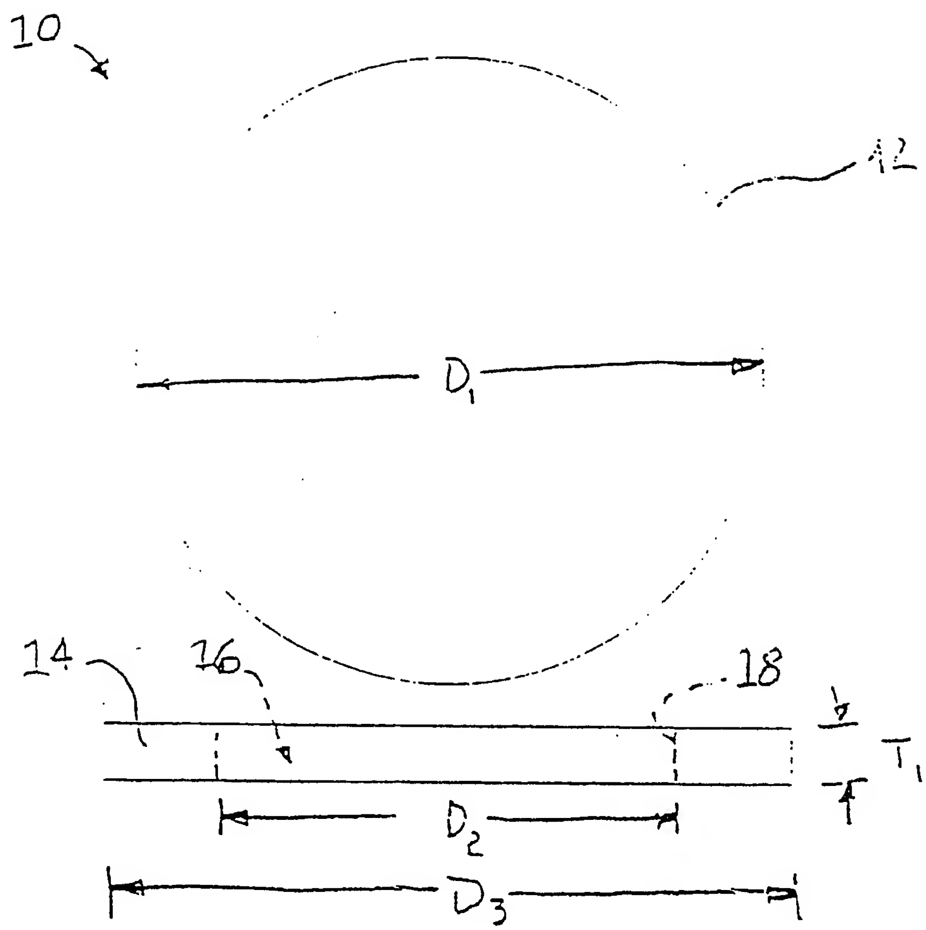

Fig. 1

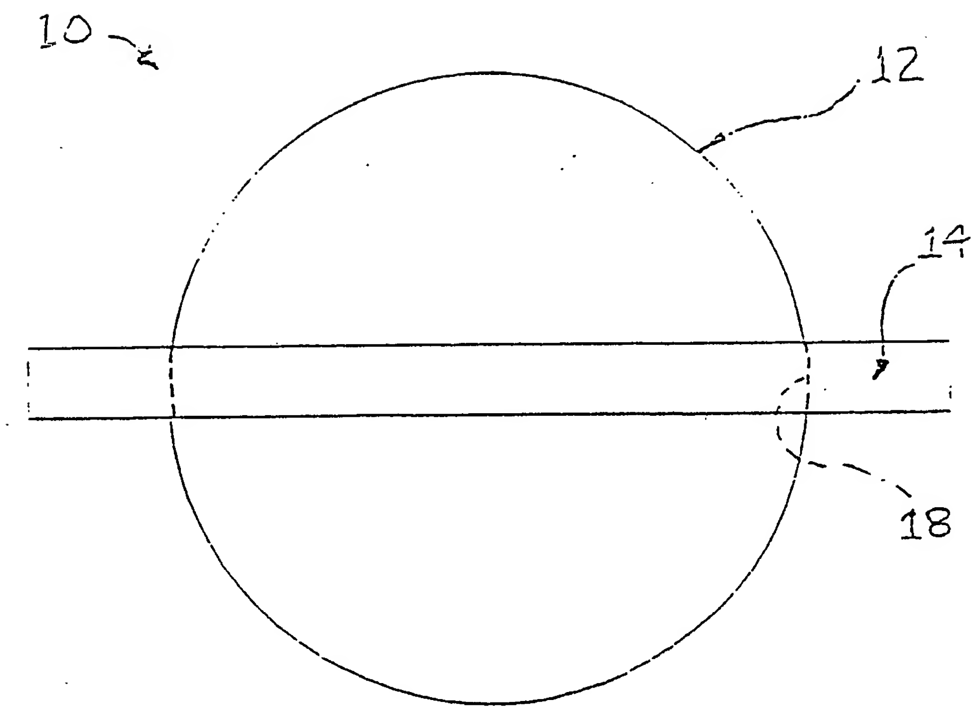

FIG 2

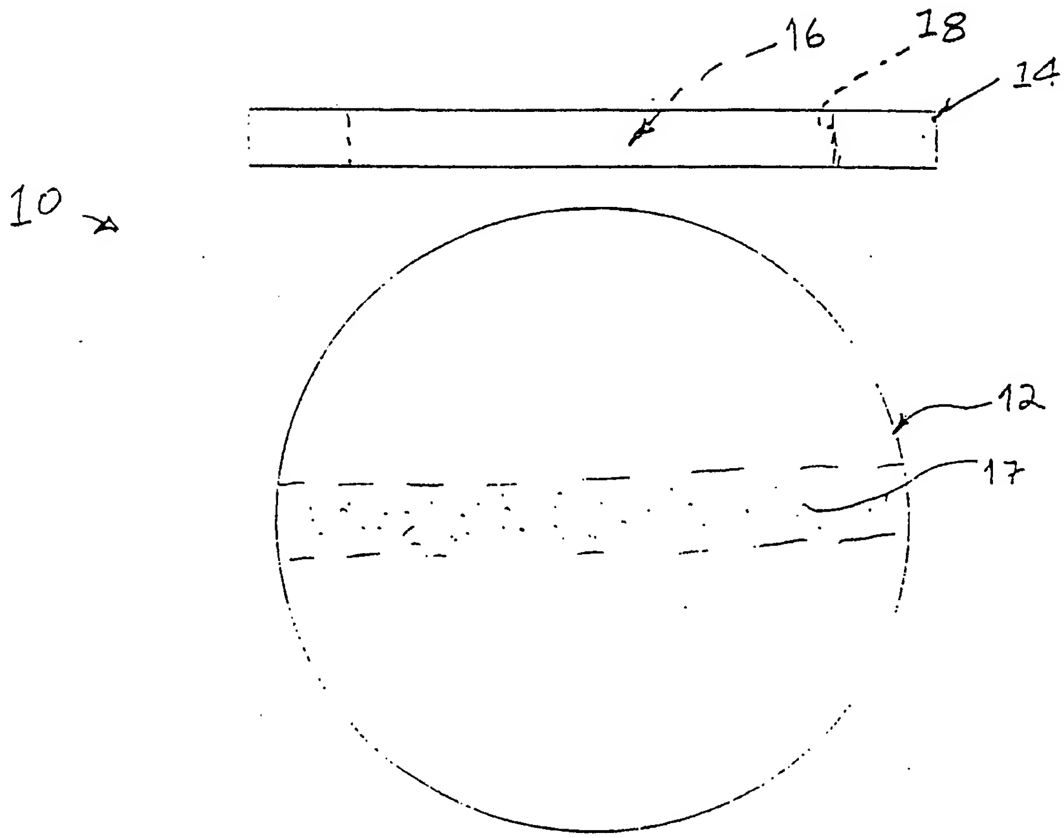

FIG. 3

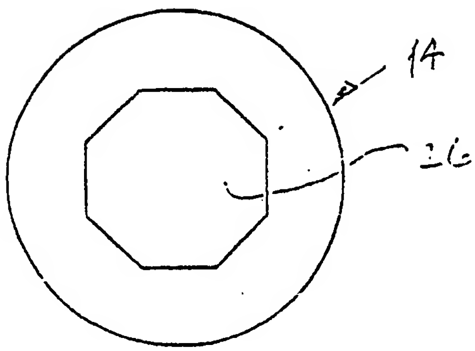

FIG. 4B

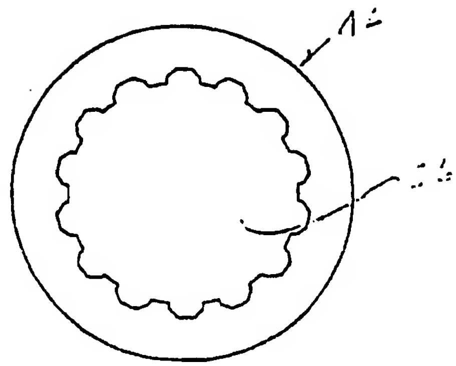

FIG. 4C

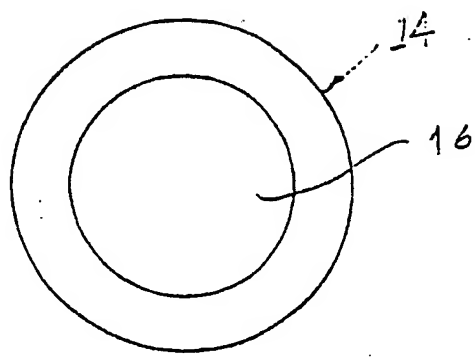

FIG. 4A

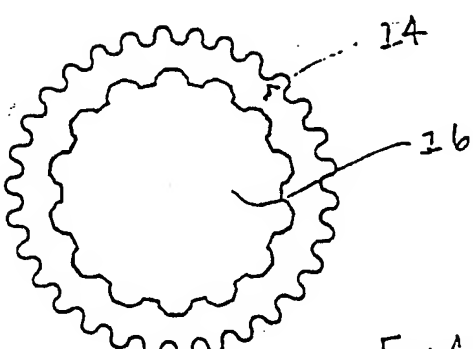

FIG. 4D

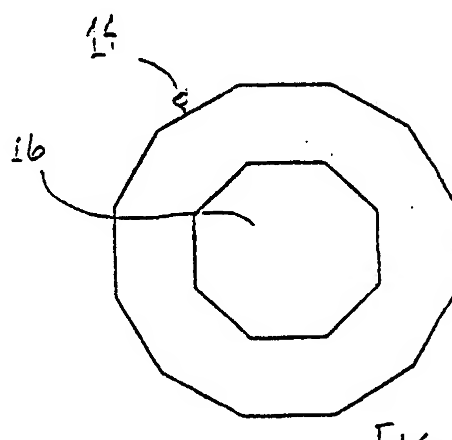

FIG. 4E

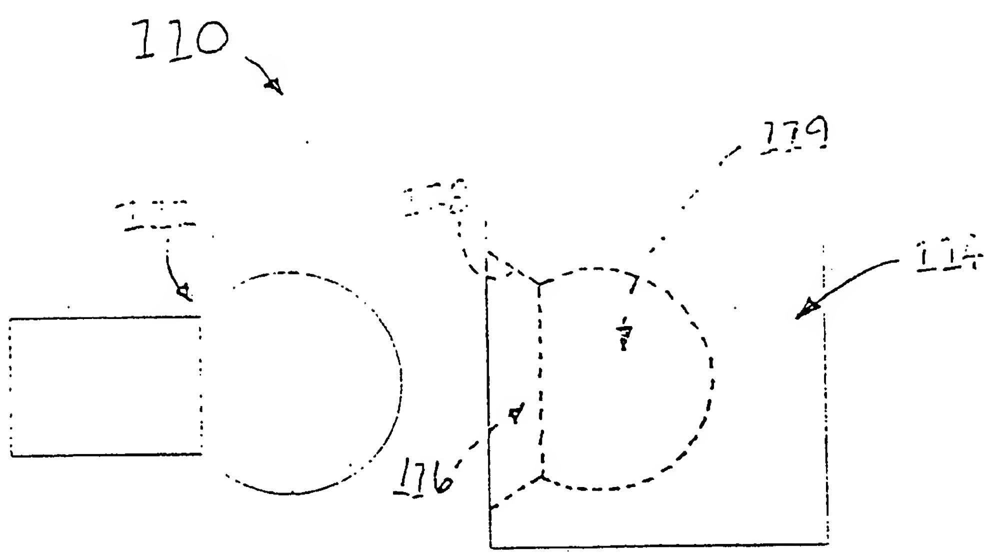

Fig. 5

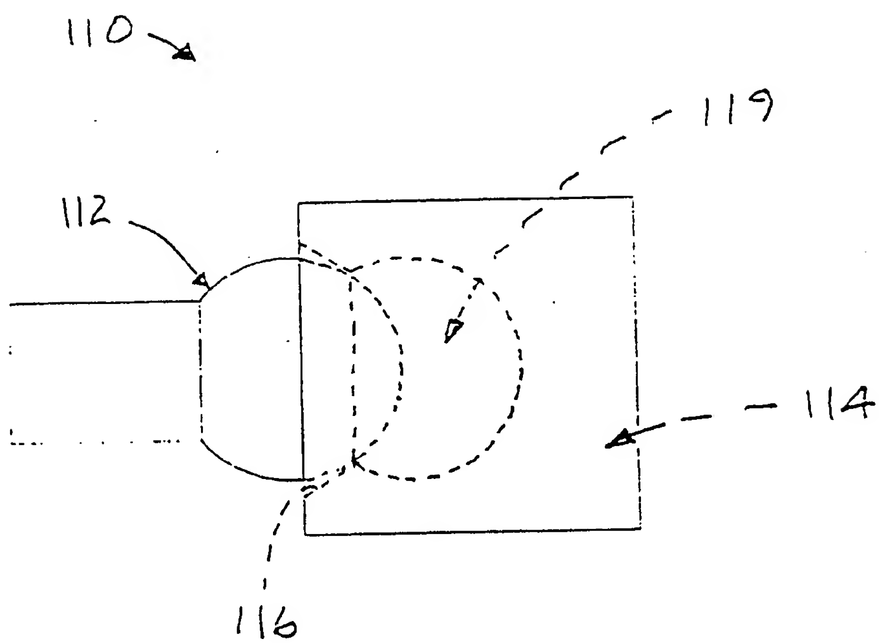

FIG. 6

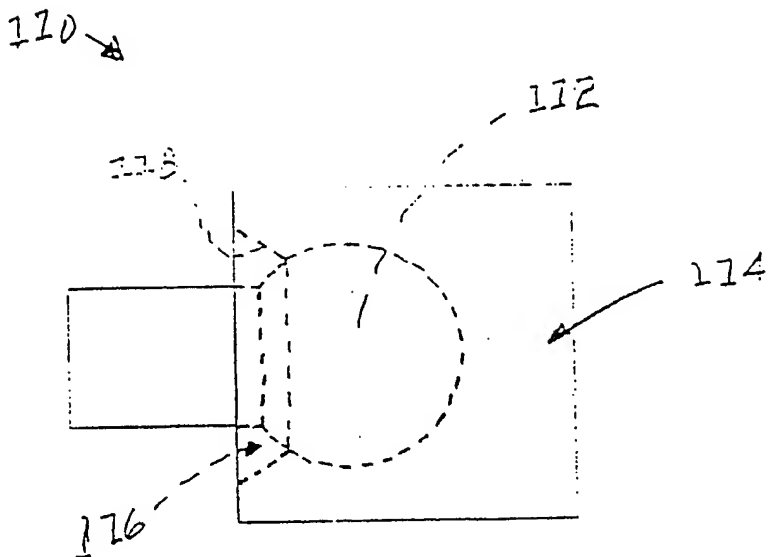

FIG. 7

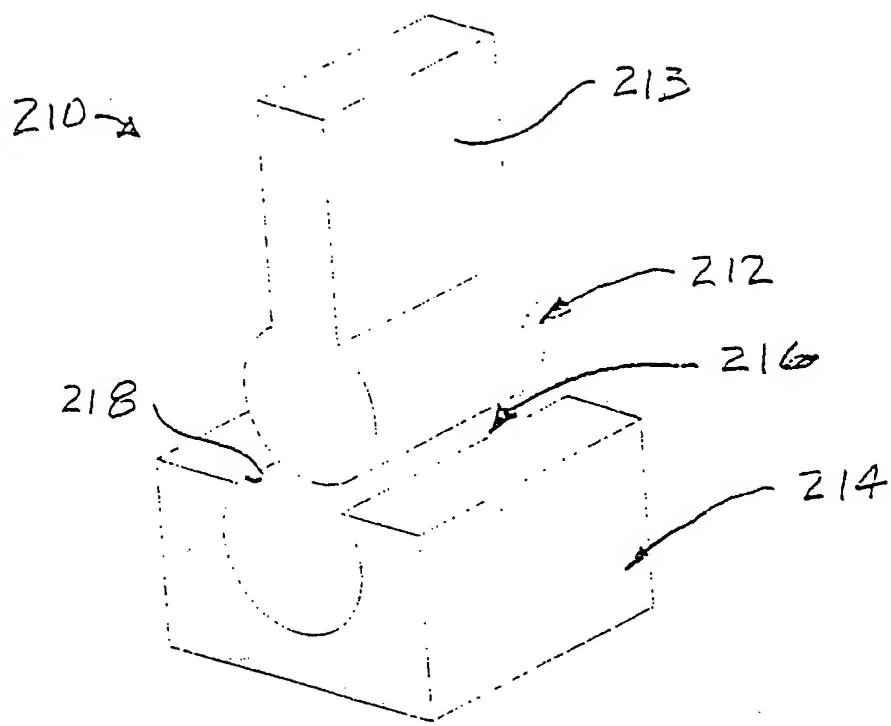

FIG. 8

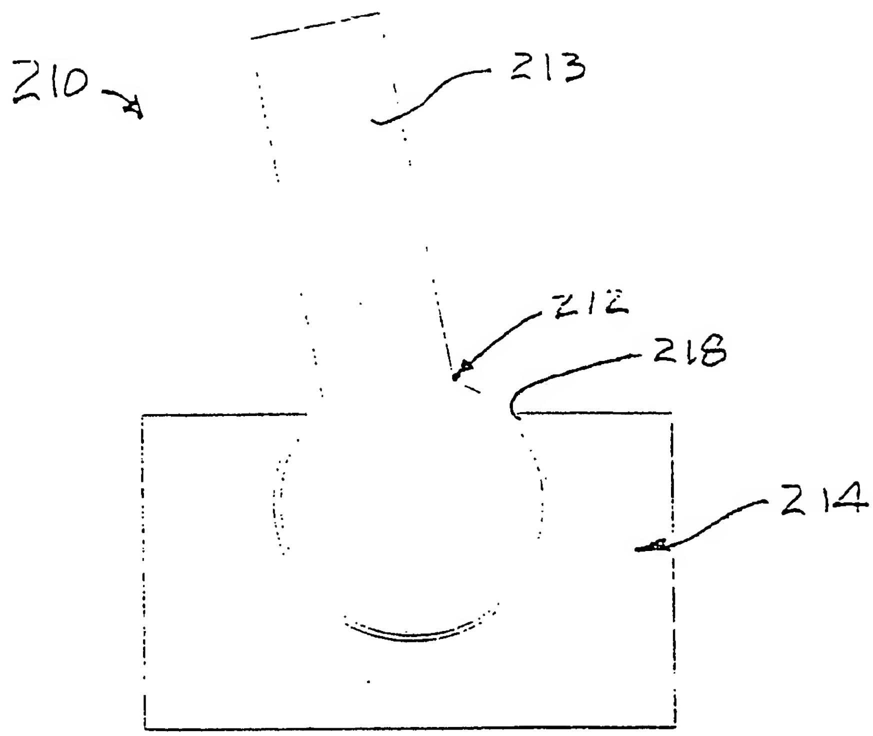

FIG. 9

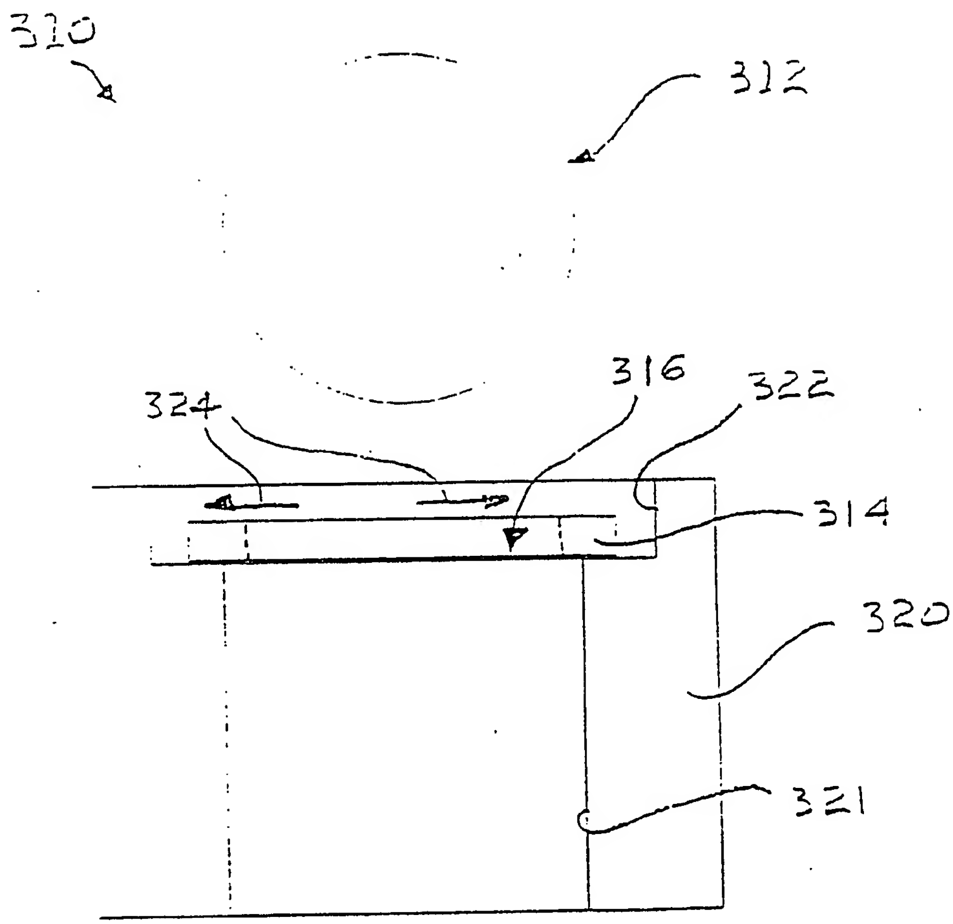

FIG. 10

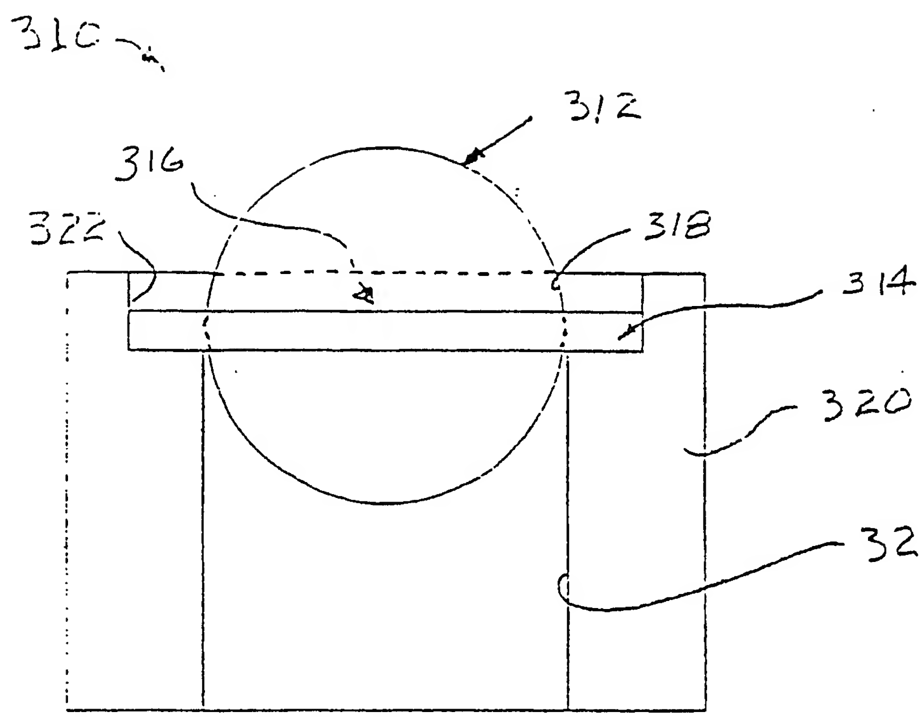

FIG. 11

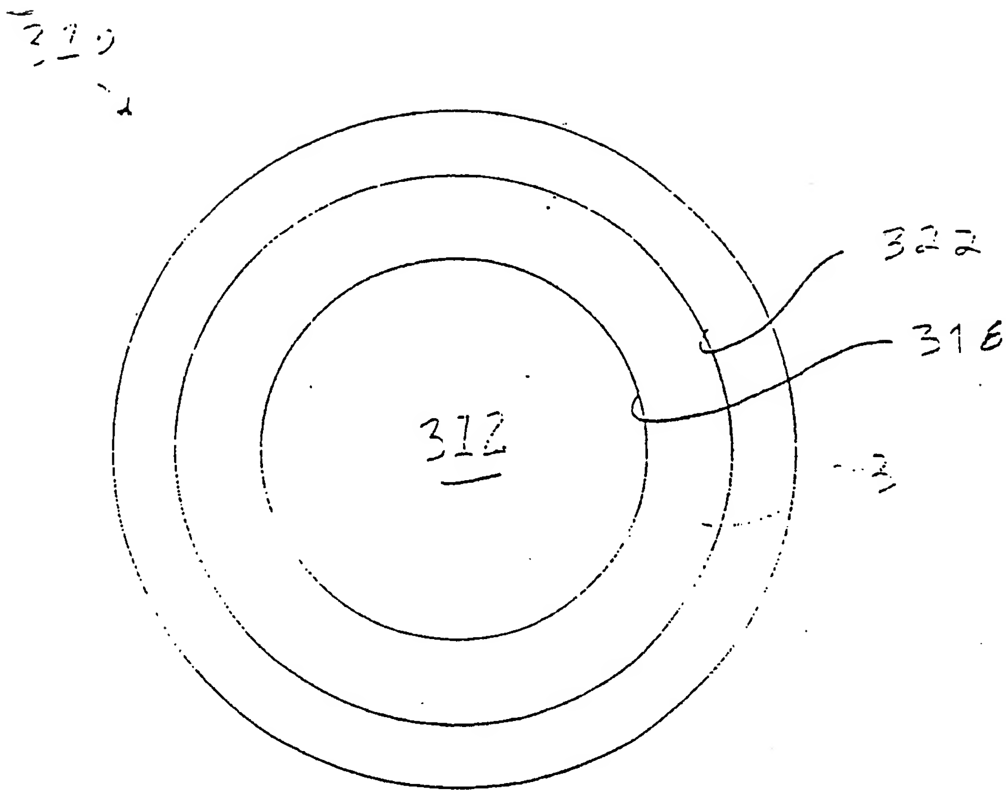

FIG. 12

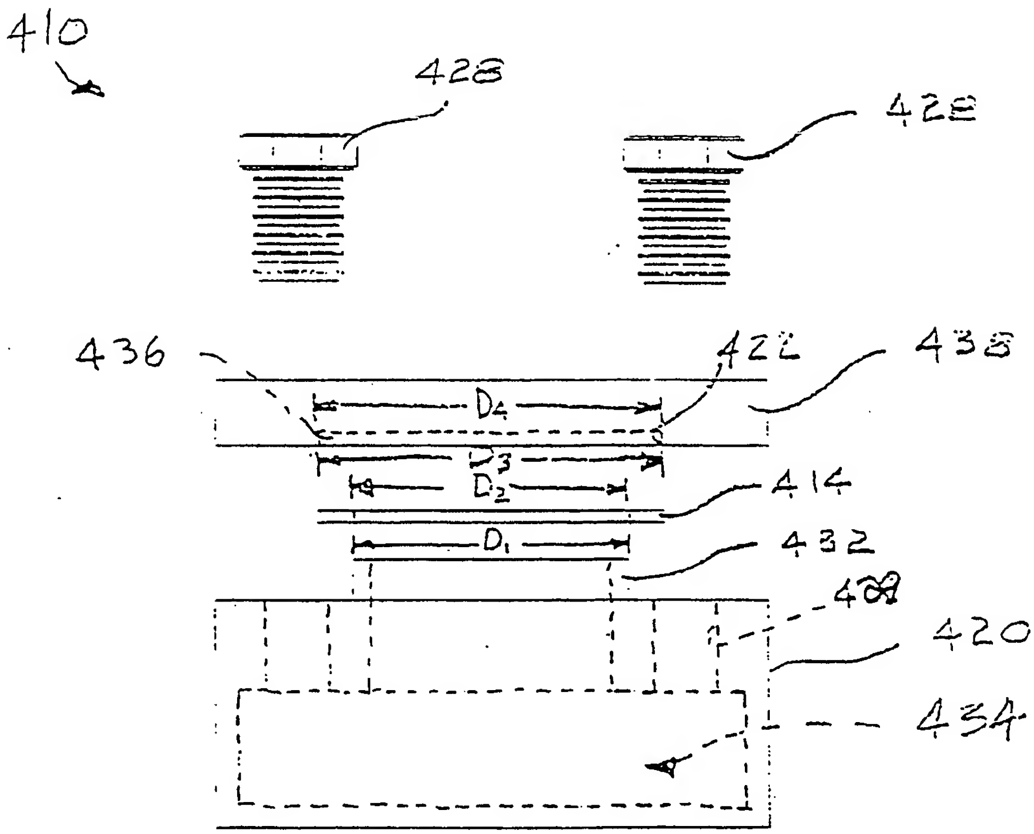

FIG. 13

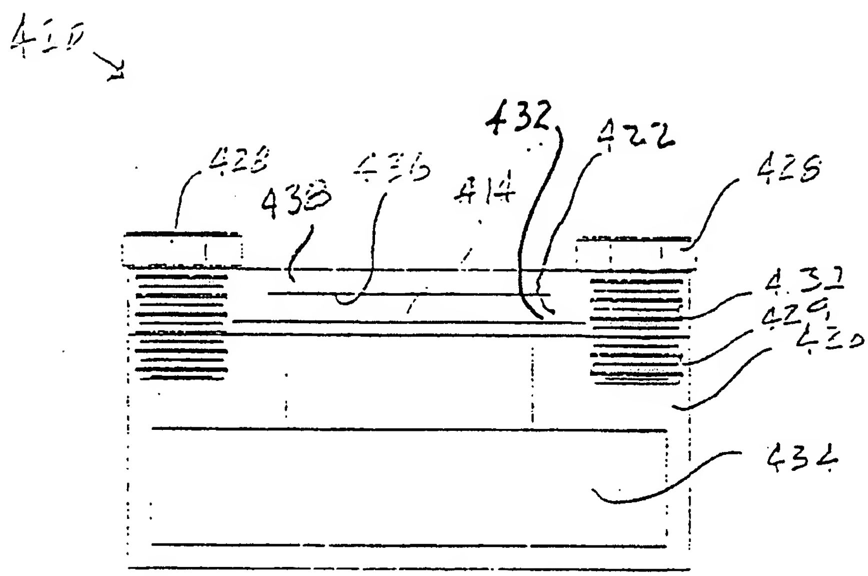

FIG. 14

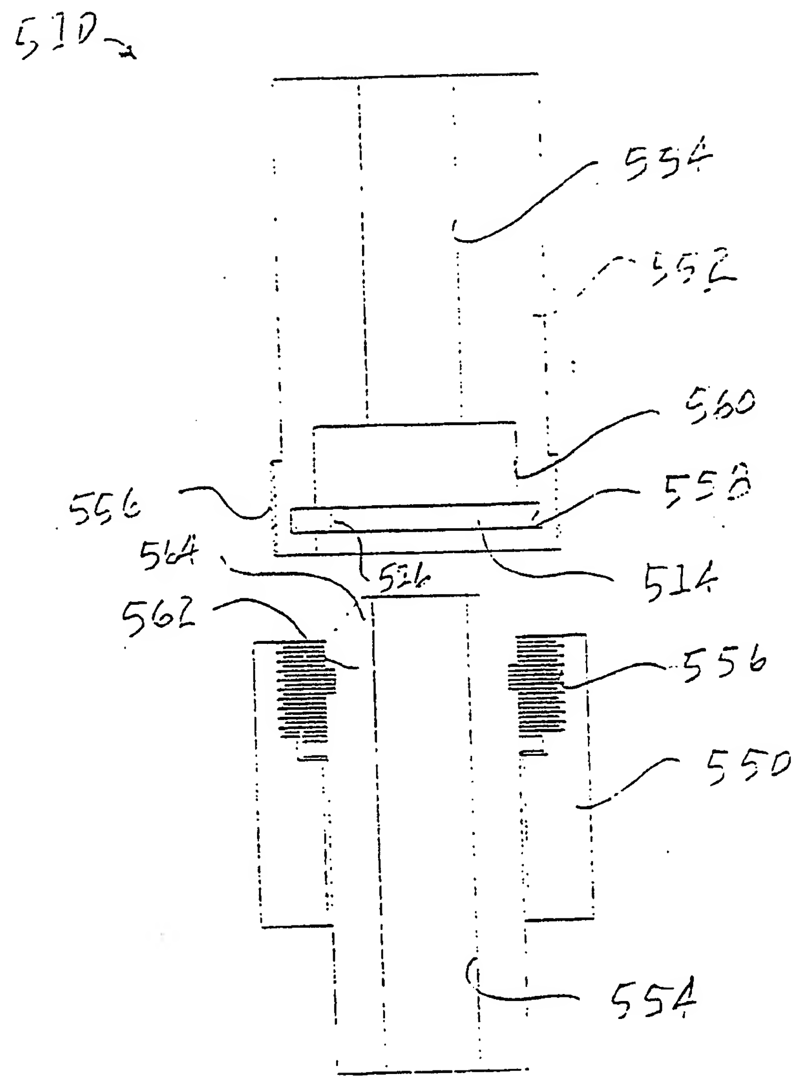

FIG. 15

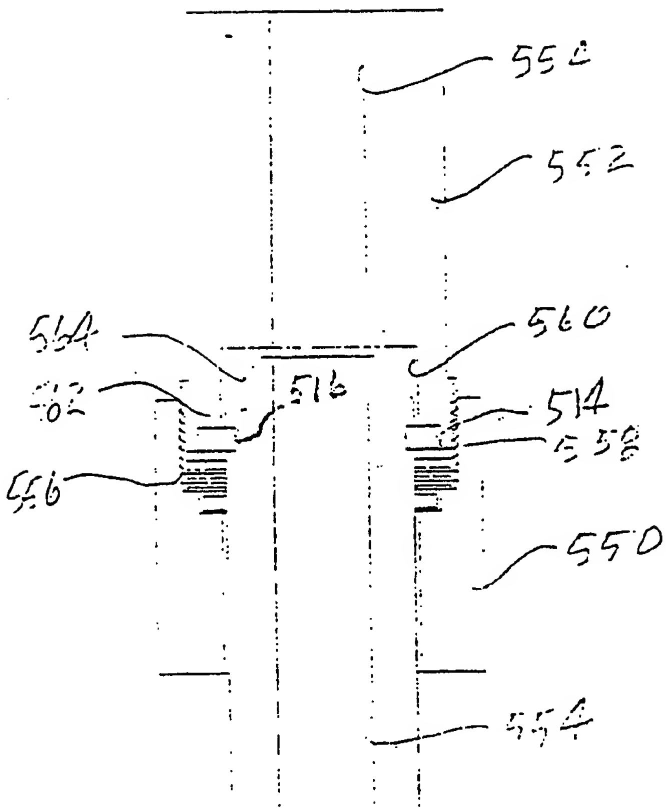

FIG. 16

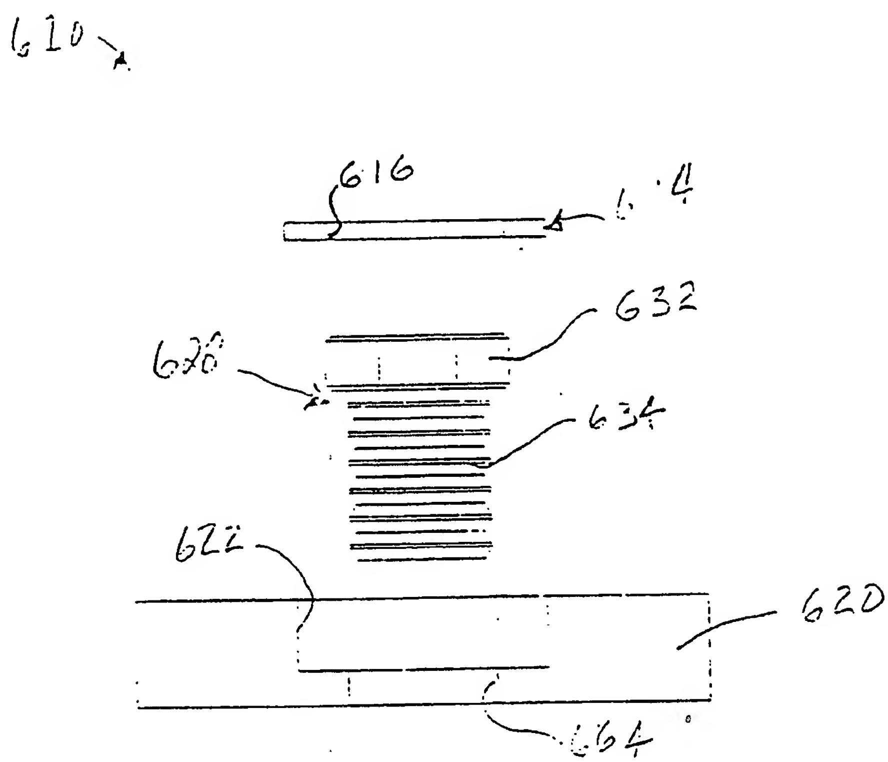

FIG. 17

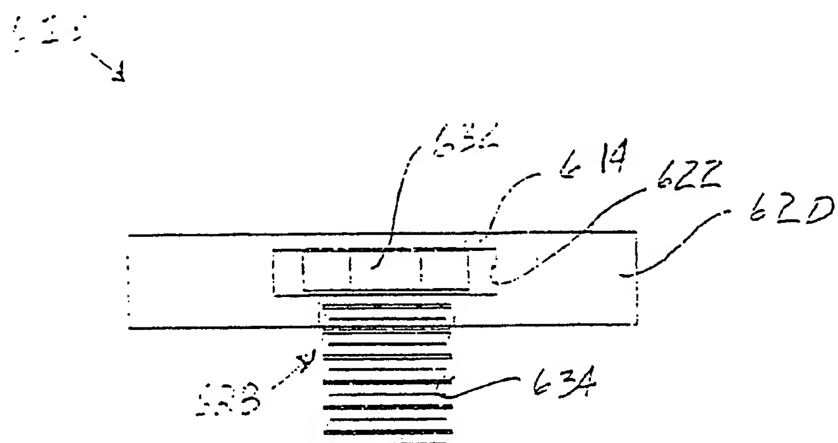

FIG 18

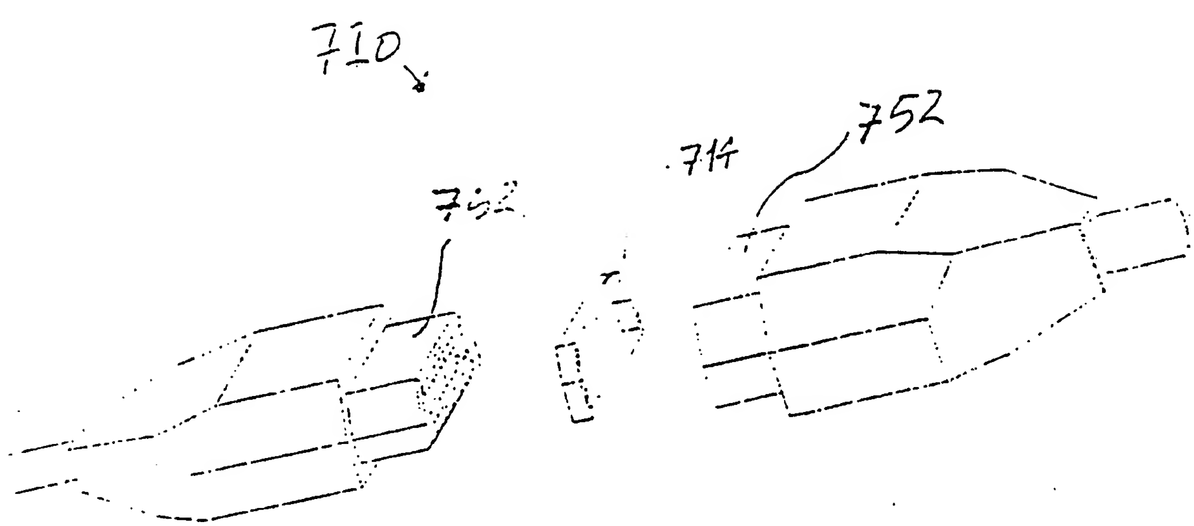

FIG. 19

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(74) Agent: CHIATALAS, John, L.; P.O. Box 8, Schooley's Mountain, NJ 07870-0008 (US).

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(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

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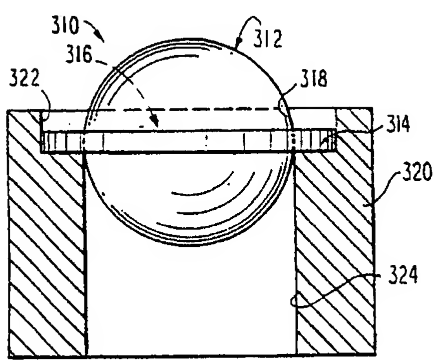
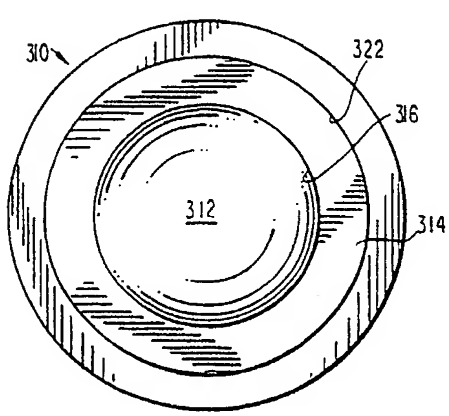
(88) Date of publication of the international search report: 25 May 2001

[Continued on next page]

(54) Title: STRESS-INDUCED SEAL



(57) Abstract: A non-corrosive metallic sealing assembly (310) is disclosed having a super-elastic component (314) made of, e.g., nitinol. The super-elastic component can expand or contract to form a seal, preferably upon mechanical stress activation using interference fit with one or more other components (312, 320) of the assembly. The improved seal is useful in fluid connectors such as hoses, electrical connectors, torque transmission devices, in vibration-dampening devices, and hinge or ball and socket joints. The assembly can seal against other components having different coefficients of thermal expansion or contraction, offering reduced temperature sensitivity during seal formation and at high performance operating conditions.



WO 00/70244 A3

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/13338

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :F16J 15/08
US CL : 277/609
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

East: nitinol, shape memory alloy

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 5,395,193 A (Krumme et al.) 7 March 1995 (07/03/95), see entire document.	1, 2, 4-6, 12, 14-20, 22, 23, 27-29, 31, 33, 34, 36, 37, 43, 45-47, and 49-51 ---------- 1, 8, 9, 30, and 44
X	US 5,226,683 A (Julien et al.) 13 July 1993 (13/07/93), see entire document.	1, 3, 8, 10, 11, 13, 19, 21, 25, 26, 33, 35, and 39-42

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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Date of the actual completion of the international search

06 SEPTEMBER 2000

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/13338

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

277/609. 613. 616, 627, 630, 650, 936: 411/542, 909, Dig: 3; 285/23, 381.1, 381.4, 381.5; 29/432, 432.1, 432.2, 515. 520. 522.1, 525, Dig. 45

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/13338

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,197,720 A (Renz et al.) 30 March 1993 (30/03/93), see entire document.	1, 2, 6, 7, 19, 20, 23, 24, 33, 34, 36-38, 45, 46
X	US 5,858,020 A (Johnson et al.) 12 January 1999 (12/01/99), see entire document.	19, 32, 33, 48
Y	US 4,880,343 A (Matsumoto) 14 November 1989 (14/11/89), see entire document.	44
Y	US 3,619,478 A (Staiger) 09 November 1971 (09/11/71), see entire document.	1,8, 9